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MULTIFUNCTIONAL AGRICULTURAL LAND USE IN A SUSTAINABLE WORLD
Design and Simulation of an Agricultural Economy Model

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Abstract

The aim of the present paper is to design a choice model for agricultural land use, in which the demand for both nutrients and bio-fuels is taken into consideration. To that end, we employ an AEM (Agricultural Economy Model) as part of a broader integrated environmental sustainability system. The AEM model in the present paper is oriented towards an application to agricultural land use in Japan. Based on an extensive data collection effort, the model is tested by means of various dynamic simulation experiments using the STELLA software. The results are interesting and demonstrate that: (i) the current energy demand in Japan exceeds the country's present energy capacity and potential; (ii) Japan tends to extract energy mainly from carbohydrates and next from proteins. The robustness of the model results is tested through various sensitivity analyses.

Keywords: multifunctional land use, nutrients, bio-ethanol, sustainable development, Agricultural Economy Model

1. Agricultural Land Use: A Sustainable Challenge

Agriculture is a major land use consumer in our world; its extraction of physical resources from the earth means a direct threat to ecological sustainability and diversity. Over the past few decades, agriculture has changed from a traditional low-tech and ecologically-benign sector into a modern high-tech industrial sector (see de Noronha Vaz et al. 2009). Clearly, agriculture is a primary food resource, but in many countries it serves increasingly as an energy resource (e.g. bio-ethanol). Consequently, agriculture is becoming a centrepiece in the worldwide sustainability debate, as food, energy, ecology and land use are concentrated here in one sector. The fundamental transformation of agriculture into a complex domain driven by modern knowledge and technologies prompts many discussions on ecological quality in agricultural areas, not only in intensive agriculture but also in low-density tropical areas.

In the past, agricultural land use served mainly a monosectoral purpose, viz. the production of foodstuffs in order to meet the multifaceted demand for nutrients in various forms. In recent decades, the sustainability movement has emphasized the need for environmentally-benign modes of agricultural production, so that the agricultural sector – the biggest land use consumer in the world – would also serve the broadly accepted policy objective of sustainable land use in an ecologically vulnerable world. And more recently, the emerging scarcity of energy – reflected in the rapid rise in oil products – has in many countries prompted a new challenge to agriculture, viz. the large-scale production of energy, mainly in the form of bio-fuel.

In recent decades there has been increased concern about ecological quality in relation to agriculture. In particular, biological diversity has received much attention in research and public policy (see Nunes and van den Bergh 2001). There is a worldwide concern about its relevance for the carrying capacity of rich but fragile ecosystems. A dominant element in recent discussions about sustainable development is anxiety about the loss of biological diversity (or biodiversity) in agriculture. Biodiversity requires our attention for two reasons. First, it provides a wide range of direct and indirect benefits to mankind that occur on both local and global scales. Second, many agricultural activities are contributing to unprecedented rates of biodiversity loss, which threaten the stability and continuity of ecosystems, as well as their provision of goods and services to mankind. Consequently, in recent years much attention has been directed towards the analysis and valuation of the loss of biodiversity.

Our world is – not only for its daily consumption and production, but also for its long-term survival – dependent on the ecosystems' resources, such as energy, water, food and wood. This has caused an increasing transformation of the earth's surface into productive land, with a subsequent loss of species and decay in biological variety. The mean species abundance – a proxy indicator for biodiversity – has shown a reduction of more than 30 per cent over the past decades worldwide. The awareness is growing that the current development is entirely unsustainable and has to be transformed into a balanced long-run development path. The recognition that biological diversity in agriculture is of critical importance for the stability of the earth's ecosystems – as a key resource for the sustainable functions of the natural systems – offers a complementary perspective to the view that biodiversity has a fundamental potential for human use, such as sustainable development, recreation, human health, or scientific research.

The above mentioned conflictual trends have in recent years become more aggravated as a result of the increasing use of agricultural land – sometimes even tropical forest – for energy production in the form of bio-fuel, in particular, bio-ethanol. To investigate the nature of these sustainability conflicts in the present paper we will employ an AEM (Agricultural Economy Model) as a particular module of a more comprehensive model for analysing global environmental sustainability, called IMAGE (Integrated Model to Assess the Global Environment), designed by RIVM (the Netherlands State Institute for Public Health and Environment). AEM is essentially rooted in macroeconomic utility theory.

This AEM model will be operationalized for the case of Japan. After an extensive data collection effort – geared towards the specificities of the agricultural sector in Japan – the model is run as a simulation model (using the STELLA software package) to identify critical threshold levels for sustainable foodstuff supply and bio-ethanol in Japan.

2. An Integrated Architecture for Sustainable Land Use Development

Agricultural activities have to be positioned in a broad framework of land-use developments, in which the production of foodstuffs and energy products plays an important role. For a proper trade-off between the production of nutrients and bio-fuel, it is critical to adopt an integrated perspective on land use, in which technology, environment, competition, land rent, markets and productivity are incorporated. The way to handle complex trade-offs between alternative land use developments should be based on economic utility and production theory, in order to ensure an optimal mix of various land use categories.

In the present paper we will use an Agricultural Economy Model (AEM) – based on economic theory – to arrive at a better understanding of the choices between nutrients (demand, intensity) and energy, against the background of an integrated land-use perspective. AEM was originally a submodel of IMAGE (Integrated Model to Assess the Global Environment), developed by RIVM (for details, see, inter alia, Alcamo et al. 1998). The original AEM system did not contain bio-ethanol, as it included only nutrients. Another limitation of AEM was that it did not differentiate nutrients in terms of proteins, fats and carbohydrates, so that a balanced food composition could not be calculated through the use of AEM. In our new AEM system, however, we have extended the variables by including both the nutrient composition and bio-ethanol, in order to assess an optimal land use composition. Thus, our AEM system has four constituents, viz. protein, fat, carbohydrate and biomass.

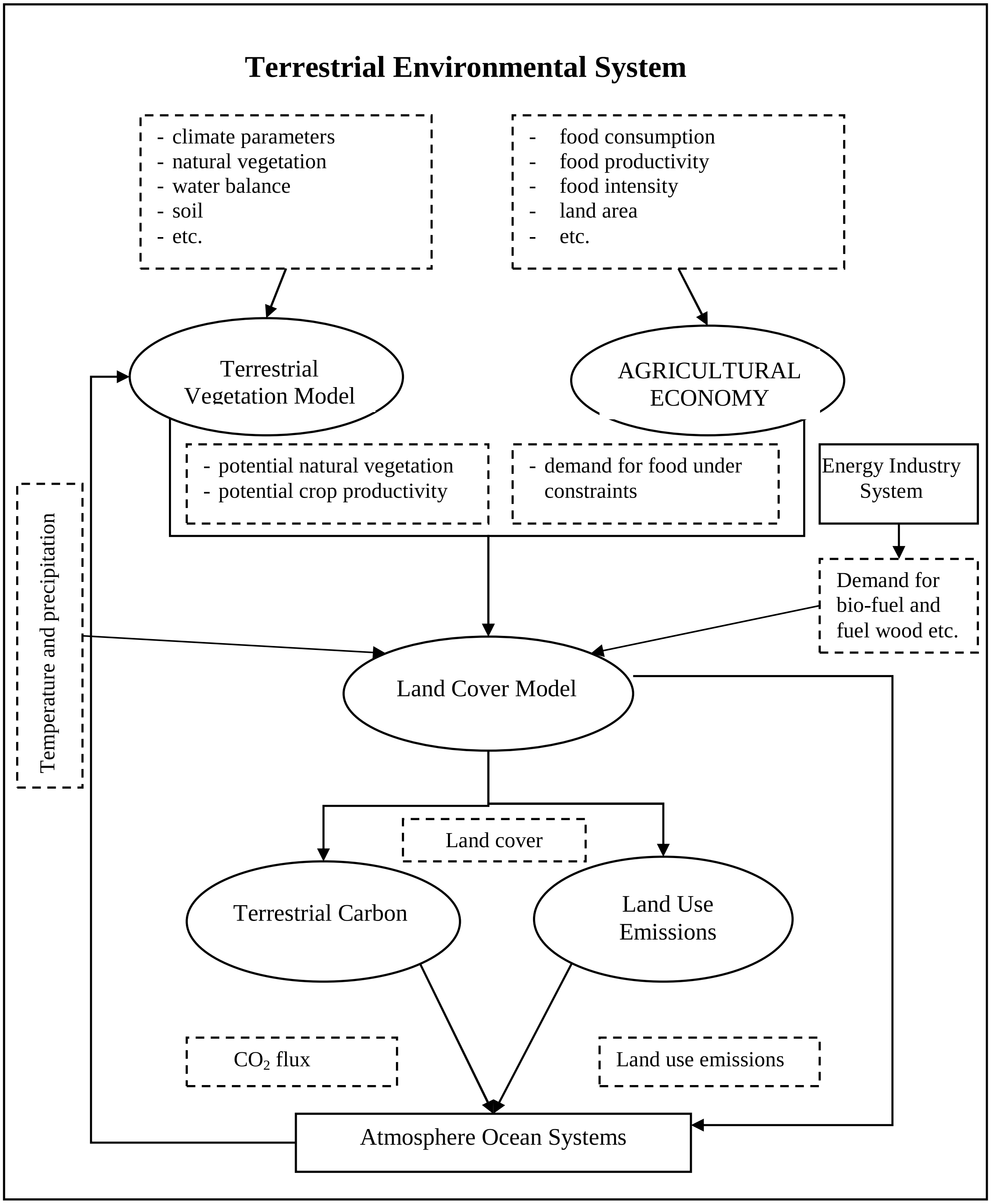
We will first elaborate on the IMAGE model as being the ‘mother model’ of a set of interconnected land use models (including AEM). The general objective of IMAGE is to explore the long-term dynamics of global environmental changes. IMAGE has gone through a series of amendments and improvements resulting in several updated versions. The basis for our research is version 2.1 which will be described here in more detail. In this version, the world is subdivided into 13 regions: namely the USA, Canada, Latin-America, Eastern Europe, Africa, the CIS (the former Soviet Union), the Middle-East, OECD Europe, India and South Asia, China and East Asia, Oceania, and Japan (see Strengers 2006).

The modelling framework of IMAGE 2.1. consists of three fully-connected main subsystems: TES (Terrestrial Environmental System), EIS (Energy-Industry Systems) and AOS (Atmosphere-Ocean System). Each of these subsystems is able to compute and simulate ecological changes that serve to map out climate changes (for a detailed description of the interactions between these models, see Alcamo et al. 1998).

AEM is a sub-module of TES, and therefore, we will only present the global structure of TES (see Figure 1 and Table 1).

Figure 1 shows that TES has five submodels, viz. TVM (Terrestrial Vegetation Model), LCM (Land Cover Model), AEM, LUEM (Land Use Emission Model) and TCM (Terrestrial Carbon Model). In the present section, we focus in particular on TVM, LCM, TCM and LUEM as major constituents of TES.

First, TVM aims to compute the potential distribution of natural vegetation and crops (see Figure 2). This is done in three stages. The first stage involves calculating climate indices concerned with frost occurrence and severity, characteristics of the growing season, and moisture availability. The studies of Prentice et al. (1992), Leemans and Van den Born (1994) and Prentice et al. (1993) deal with the characteristics of growing seasons. Next, Prentice et al. (1992) focus on frost occurrence and severity, while Prentice et al. (1993) handle moisture availability.



Source: Alcamo et al. (1998, p. 14)
Legend: Food means crops, potatoes, starch, vegetables, fruits, meats, daily products etc. There are roughly 16 food categories.

Figure 1. Flow diagram and interrelationships between five submodels

Table 1. Overview of information in submodels in TES

From	**To**	**Information**
AEM	LCM	Demand for food and feed Demand for timber Demand for bio-fuels
AEM	LUEM	Number of animals Feed consumed by animals
TVM	LCM	Potential vegetation Potential crop productivity
TVM	TCM	Soil moisture
TVM	LUEM	Soil moisture
LCM	AEM	Land quality indicators[1]
LCM	TCM	Land cover (changes)
LCM	LUEM	Land cover (changes) Extent of cropping areas Production of food crops
TCM	LCM	Carbon content of vegetation
TCM	LUEM	Carbon fluxes due to biomass burning Carbon content of vegetation

Source: Alcamo et al. (1998, p. 25)

Legend:
AEM = Agricultural Economy Model
TVM=Terrestrial Vegetation Model
LCM = Land Cover Model
TCM= Terrestrial Carbon Model
LUEM= Land Use Emission Model

Note:
[*]LCM used the data for bio-fuel and fuel wood from the Energy Economy Model in another subsystem (Energy Industry System), the data estimated by another subsystem (Atmosphere Ocean System) are used as feedback data in both TVM and TCM.
[**]'Land quality indicators' are not addressed in this paper.

During the second stage important results from the TVM calculation are presented in a modified version of what is called the BIOME model, which is a calculation method to determine the potential distribution of major plants in the ecosystem. BIOME is basically driven by NPP (Net Primary Productivity) which is calculated by the relationship between photosynthesis and respiration (see Prentice et al. 1992). All plants can grow under favourable conditions, such as temperature, CO_2 concentration, soil, moisture availability, and so on. Therefore, the modified BIOME uses climate indices in the first stage to determine the potential distribution of plant types. The plant types can be categorized in three types: needle-leaf vs. broadleaf; deciduous vs. evergreen; trees vs. shrubs and grasses. These distribution data are combined into biomass, and then calculated. The main difference between the modified BIOME and the original BIOME is that NPP storage clearly distinguishes tundra area from wood tundra area. In addition, the modified BIOME takes into account tropical regions to overcome shortfalls in the original BIOME (see Alcamo et al. 1998, p. 16).

Terrestrial Vegetation Model

1st components: *Climate indices*
to calculate **climate indices** including the following data:

- frost occurrence and severity (see Olson et al. 1985)
- characteristics of the growing season (see Kreilman and Bouwman 1994)
- moisture availability (see Prentice et al. 1992)

↓

2nd components: *Modified BIOME* model (see Olson et al. 1985)
to calculate the **potential distribution of major plants:**

- needle-leafed vs broad-leafed, deciduous vs. evergreen
- trees vs. shrubs and grasses

↓

3rd components: *Agro-ecological zone approach* (FAO Crop Sustainability Model)
to calculate the **potential distribution of different crops:**

- Temperate cereals, rice, maize, tropical serials, pulses, oil crops, sugar corn, maize, woody biomass etc.

From	To	Information
TVM	LCM	Potential vegetation Potential crop productivity
TVM	TCM	Soil moisture
TVM	LUEM	Soil moisture
AOS	TVM	Feedback data

Figure 2. Information flow diagram in TVM

The third and final stage relates to the Agro-Ecological Zone (AEZ) approach (see Alcamo et al. 1998, p. 16). The AEZ approach uses a land resources inventory to evaluate all feasible agricultural land-use options for specific management conditions and levels of input. The purpose of this AEZ is to determine the potential distribution of different crops. For example, if a certain crop or plant has grown under different conditions, i.e. in a cold area or a warm area, it is generally plausible to assume that a plant raised in the warmer area would be bigger than one raised in a cold area. This is the reason why several calculations of potential distributions of different crops are conducted under conditions related to local climate. The AEZ uses digital global databases such as those containing information about topography, soil, terrain, and land cover. In an FAO (1978) report the various steps are described as follows: "*First, AEZ provides a standardized framework for characterizing climate, soil, and terrain conditions relevant to agricultural production. The concepts of Length of Growing Period (LGP) and of latitudinal thermal climates have been applied in mapping activities focusing on zoning at various scales, from the sub-national to the global level. Second, AEZ matching procedures are used to identify crop-specific limitations of prevailing climate, soil, and terrain resources, under assumed levels* *of inputs and management conditions. This part of the AEZ methodology provides maximum potential and agronomically attainable crop yields for basic land resources units (usually grid-cells in the recent digital databases). Third, AEZ provides the frame for various applications. The previous two sets of activities result in very large databases. The information contained in these data sets forms the basis for a number of AEZ applications, such as quantification of land productivity, extent of land with rain-fed or irrigated cultivation potential, estimation of the land's population supporting capacity, and multi-criteria optimization of land resources use and development."*

Next, the aim of the LCM is to simulate changes in land cover by reconciling the demands for land use with the potential of land (see Figure 3). The basic idea of the LCM is to change the gridded land cover within a world region until the total demand for the region is satisfied. In the LCM the world area is divided by grid cells (0.5 degree latitude and 0.5 degree longitude) and then each divided grid cell is given a cell name. Following this, the results of another model – AEM, TVM and EEM (Energy Economy Model in Energy Industry System) – are inputted into the LCM in order to simulate land cover in a grid cell.

The previous LCM uses output data calculated by the ADM (Agricultural Demand Model) and the TVM. The output of the ADM is the demand for land use, with the assumption that the demand for land required to produce all food is related to population and economic growth, while the results in the TVM concern the potential distribution of land which means major plants (needle-leaf vs. broadleaf, deciduous vs. evergreen, tree vs. shrubs and grasses) and different crops (temperate cereals, rice, maize, tropical cereals, pulses, oil crops, sugar cane, wood biomass, and so on.). The aforementioned has been the procedure in LCM up to and including IMAGE 2.0.

After IMAGE 2.1, the LCM was improved in order to solve several problems such as the computing of feed demand, the allocation of bio-fuel, the method for computing timber demand, and algorithms for computing the transient response of natural vegetation. As mentioned before, "the demand for land use" with the "potential of land" is necessary to simulate land cover transformation. After IMAGE 2.1, the LCM uses "regional demand for all products" calculated by the AEM and EEM instead of "the demand for land". With regard to "potential of land", the results of the TVM, the grid-based potential vegetation and productivity, are used.

The data which has served as input to the LCM is basically the database used by Olson et al. (1985) and tabular data of natural statistics provided by international organizations like FAO Agrostat. However, there are some problems with the relationship between Olson's database and FAO Agrostat. For example, the geographic distribution of crops and forest cannot be derived from FAO Agrostat. Furthermore, the amount of agricultural land in FAO Agrostat is different from that in Olson's database.

Land Cover Model

Goal: to simulate land cover transformation on a global grid by reconciling ‘the demand for land use’ with ‘potential of land’

Previous basic concept

‘demand for land use’ → by ADM[1]

‘potential of land’ → by TVM using grid cell

Assumption in ADM (see Zuidema et al. 1994):
population and economic growth are strongly related to the demand for food

Improved and additional factors:

‘regional demand for all products required by LCM’ → data input by EEM[2]

‘grid-based potential vegetation’ → data input by AEM

‘grid-based potential productivity’ → data input by TVM

- new method for computing feed demand
- allocation of bio-fuel
- method for computing timber demand
- algorithms for computing the transient response of natural vegetation

land cover transformation --input--> other systems

[1] Agricultural Demand Model.
[2] Energy Economy Model in EIS (Energy Industry System).

From	To	Information
LCM	AEM	Land quality indicators
LCM	TCM	Land cover (changes)
LCM	LUEM	Land cover (changes) Extent of cropping areas Production of food crops
AEM	LCM	Demand for food and feed Demand for timber
TVM	LCM	Potential vegetation Potential crop productivity
TCM	LCM	Carbon content of vegetation

Figure 3. Information flow diagram in LCM

Therefore we have to process this data so that it can serve as database for the LCM.

First, grid cells are specified as land cells according to the Olson Database of World Ecosystem Version 1.4D (Kineman 1992), the digitized version of the FAO Soil Map of the World (FAO 1978), and the CLIMATE database (Leemans and Cramer 1991).

Secondly, land cells are assigned as irrigated agricultural land by ranking cells. Ranking a cell means it represents preference ranking with “land use rules”, for instance, close to large river or others bodies of water, or has high potential crop productivities, etc. Grid cells within a country are allocated as irrigated land until the total irrigated area within a country complies with the estimate reported in FAO Agrostat.

Next, the land cells are allocated as non-irrigated agricultural land similar to the procedure described above.

Fourthly, the area within particular agricultural cells is assigned to specific crops. Allocated specific crops are based on: an estimation from FAO Agrostat, the potential productivity of crops simulated by TVM, and information about the density of animals.

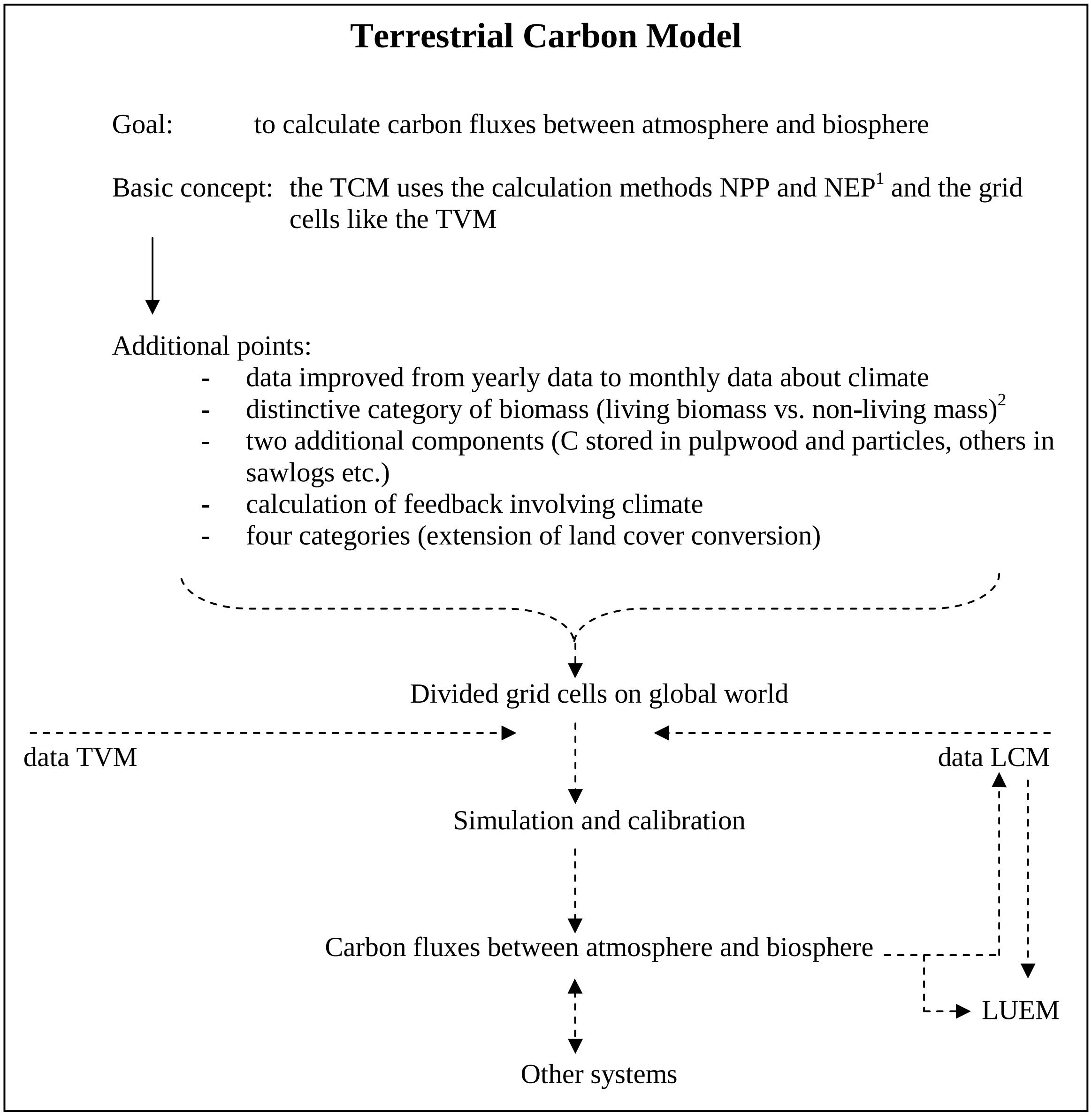
After preparing the database, the data is processed in order to simulate the results which concern land cover transformation on the global grid by reconciling “the demand for land use” with “potential of land”. The output of the LCM serves as input to the other models such as AEM, TCM (Terrestrial Carbon Model), as well as LUEM (Land Use Emission Model).

The AEM is different from the two models which were described above, in that it is based on a theoretical economic model. Therefore, we will explain AEM in more detail in Section 3.

There are two more modules in the second part, the TCM and the LUEM. These two models are similar in way they calculate gas emission. Each model uses the grid cell and the results (land cover data) in the Land Cover Model.

The aim of the TCM is to calculate the carbon fluxes between the atmosphere and the biosphere (see Figure 4). This model, similar to the TVM, uses a special grid to calculate the carbon fluxes. The main factor in the TCM is the NPP (Net Primary Productivity) calculation, where NPP means plant photosynthesis minus plant respiration. Moreover, the NPP minus soil respiration between the atmosphere and biosphere equals the net carbon fluxes, which is called NEP (Net Ecosystem Productivity). Thus can be shown as follows: NEP = NPP – soil respiration.

The basic structure of the TCM between versions 2.0 and 2.1 has not changed substantially: (1) the carbon dioxide in the atmosphere is calculated by NPP, and these results are grouped in several categories – root, leaf, branch, and stem – in the biosphere; (2) the allocated data has sifted the non-living biomass from living biomass by degree (TCM version 2.0 is described in detail in Goldewijk et al. 1994). These calculations for carbon fluxes use grid cells and other data from the TVM, the LCM, and the AEM.



[1] NPP= Net Primary Productivity, NEP is Ecosystem Productivity. The former indicates plant photosynthesis minus plant respiration, the latter indicates NNP minus soil respiration.
[2] Living biomass indicates leaves, branches, stems, roots; non-living biomass indicates litter, humans and charcoal

From	To	Information
TCM	LCM	Carbon content of vegetation
TCM	LUEM	Carbon content of vegetation Carbon fluxes due to biomass burning
TVM	TCM	Soil moisture
LCM	TCM	Land cover (changes)

Figure 4. Information flow diagram in TCM

Since version 2.1, the TCM has been improved in some points in order to simulate better results. First, the quality of the data improves from yearly to monthly data. Second, it takes into account carbon stored in other biomass, such as pulpwood and particles, saw logs, veneer, and industrial round wood. Other improvements relate to the calculation of feedbacks involving climate and the extension of land cover conversion from two to four categories.

Regarding the land cover impact on both NPP and NEP, the land cover conversion is divided into four categories: from natural vegetation to agricultural land; from agricultural land to natural land cover types; from forests to re-growth forests; and from one type of natural vegetation to another. These last two categories have not been considered in TCM version 2.0.

The result of carbon fluxes are calculated at various times until change in the results of some vegetation from the TVM, the LCM and the AEM either remains stable or the period under review ends. These results are then used for the LCM and the LUEM in the TES.

Finally, the purpose of the LUEM is to compute the emissions of different greenhouse gases and ozone precursors stemming from land use and biotic sources (see Figure 5). This model is similar to the TCM described in a previous section in this paper as far as the point of gas emission is concerned. It differs, however, when dealing with other gases. The TCM only simulates carbon fluxes, while the LUEM focuses on several greenhouse gases without CO_2. In other words, other greenhouse gases, such as CH_4, CO_2 N_2O, NO_X, VOC and SO_X, are processed in LUEM.

The previous LUEM is described in detail in Kreilman and Bouwman (1994). Compared with the previous LUEM, there are a few minor improvements. The main change is the improved method for computing CH_4. The previous LUEM used the results – regional number of animals – in the AEM to estimate the greenhouse gases but this case does not take into account the productivity of these animals or the feed they consume. That is why the calculation of CH_4 has improved the EPA approach in the AEM. Another improvement relates to a new method to compute fertilizer use. This new method computes the extent of agricultural land times a fertilizer application rate per hectare. In this model, data from all submodels in TES are used and are added to the grid cells on a global scale. The data which is added consist of the following:

- the AEM provides data concerning “demand for feed” and “number of animals”;
- the TVM provides information of soil moisture estimated by the results –distribution of natural vegetation and crops;
- the LCM provides data for land cover changes, extent of cropping area and population of food crops; and
- the TCM provides carbon fluxes and carbon content of vegetation. The results of the LUEM can then also serve as input for another system (Atmosphere-Ocean System). We will now describe AEM in more detail.

Land Use Emission Model

Goal: to compute the emission of different greenhouse gases and ozone precursors

Basic concept: the LUEM uses many data from other submodels and grid cells like others

↓

Improvements:

- method to compute CH_4 emissions of animals
  - problem: no concern for the productivity of animals
  - solution: EMPA approach in AEM
- method to compute fertilizer use (N_2O emission)

Number of animals
Consumed feed

Land cover (changes)
Extent of cropping areas
Production of food crops

AEM data

LCM data

TVM data

TCM data

Soil moisture

Carbon fluxes due to biomass burning
Carbon content of vegetation

Simulation

Emission of different greenhouse gases and ozone precursors

Other systems (Atmosphere-Ocean System)

From	**To**	**Information**
AEM	LUEM	Number of animals Feed consumed by animals
TVM	LUEM	Soil moisture
LCM	LUEM	Land cover (changes) Extent of cropping areas Production of food crops
TCM	LUEM	Carbon fluxes due to biomass burning Carbon content of vegetation

Figure 5. Information flow diagram in LUEM

3. Utility Interpretation of AEM

The basic concept[1] of AEM is to consider a simplified world with only one region and a demand for nutrient d. The demand for these products, represented by d_1 and d_2, are placed on the x-axis and the y-axis in Figure 6 below. This concept is similar to the basic utility function theory. But price and money terms do not exist in this concept. We use the "land use intensities" of nutrients and bio-fuel as a proxy for prices, assuming that a high intensity product has scarcity value and a low intensity product is of low value. Land use intensities are calculated as the amount of land required to produce food products; the main variable of intensity is denoted in units of km^2 per kcal product.

The core of this approach consists of two components. The first component is the general utility function which is well known as the Cobb-Douglas function. It states that we behave rationally to maximize individual utility. Therefore, we select the optimal point at which we desire some nutrients and bio-fuels. The second component entails the constraints that are associated with real land area. The optimal point is estimated taking these constraints into account.

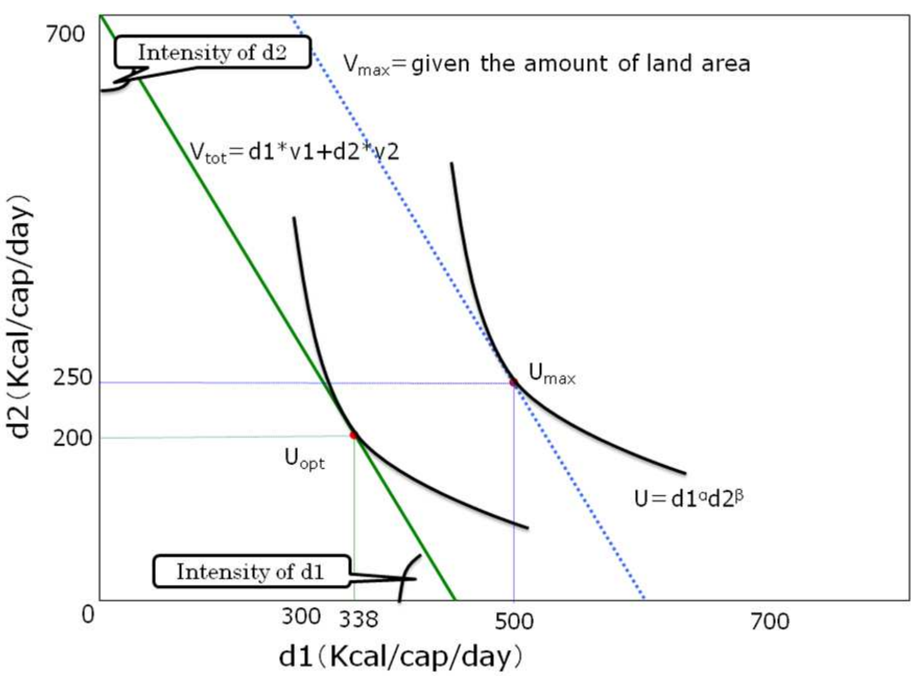


Figure 6. Basic utility of AEM

[1] We introduce only the basic concept of AEM. The utility function in this part is not different from the one in the original AEM (see Alcamo et al. 1998). We use a general Cobb-Douglas utility function here instead of a specific utility function.

The formulas that will be referred to are as follows:

$$\max U = d_1^{\alpha} \times d_2^{\beta} \qquad [1]$$

$$\text{s.t.} \quad d_1 * v_1 + d_2 * v_2 \leq V_{tot}, \qquad [2]$$

where:

d_1, d_2 diet food product (kcal/cap/day);

U utility of the diet;

v_1, v_2 intensity (m^2/kcal);

V_{tot} available budget for the utility function, expressed in m^2/cap;

V_{max} amount of land (or budget) that would be needed to produce the preferred diet;

α, β parameters of Cobb-Douglas utility function.

I would now like to change the basic concept model to the model shown below. The y-axis is bio-ethanol and the x-axis is nutrients. The first model is a two-product model, the second model is a multi- product model including bio-fuel.

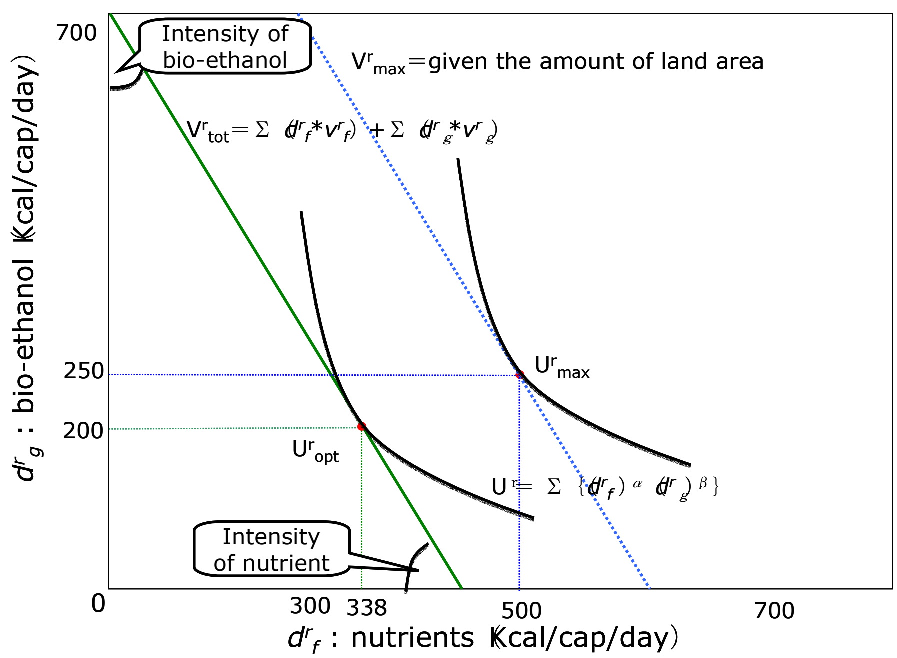


Figure 7. Expanded basic utility concept of AEM

The improved formulas that will be referred to are as follows:

$$\max U = \sum_{f=1}^{n} \sum_{g=1}^{m} \left((d_f^r)^{\alpha} \times (d_g^r)^{\beta} \right) \qquad [3]$$

$$s.t.\ \ \sum_{f=1}^{n}\left(d_f^r \times v_f^r\right)+\sum_{g=1}^{m}\left(d_g^r \times v_g^r\right)\le V_{\max}\ , \qquad [4]$$

where:

f	index for nutrients (f =1,…,n);
g	index for bio-ethanol (g=1,…,m);
r	index for region (r=1,…,ℓ);
$d^r{}_f$	the demand for "nutrients";
$d^r g$	the demand for "bio-ethanol" (kcal/cap/day);
$\max U^r$	the maximum utility of the demanded diet ($d^r{}_f$, $d^r{}_g$);
$v^r{}_f$,	the intensity for "nutrients"
$v^r{}_g$	the intensity for "bio-ethanol" (m^2/kcal/year);
$V^r{}_{tot}$	the actual budget for the utility function in year t (m^2/cap);
$V^r{}_{max}$	the amount of land (or maximum budget) needed to produce the preferred diet;
α,β	the parameter of the Cobb-Douglas utility function.

We can next calculate the optimal solution by maximizing formula [1] within a given budget[2]. First, we assume that the required nutrient is divided into three categories; protein, fat, and carbohydrate. We need to insert three categories of nutrients in order to live healthily from a nutritional science point of view. So formulas [1] and [2] can be rewritten as:

$$\max U_r=\left(d_{pf}^r\right)^{\alpha}\times\left(d_{ff}^r\right)^{\gamma}\times\left(d_{cf}^r\right)^{\varepsilon}\times\left(d_g^r\right)^{\beta} \qquad [5]$$

$$s.t.\ \ \left(d_{pf}^r\times v_{pf}^r\right)+\left(d_{ff}^r\times v_{ff}^r\right)+\left(d_{cf}^r\times v_{cf}^r\right)+\left(d_g^r\times v_g^r\right)\le V_{\max} \qquad [6]$$

Moreover, we need to take into account information from nutritional science when estimating the optimal solution. Generally speaking, the Japanese population ranks rather high; the standard ratio among the three categories is in general: 27 per cent (protein), 13 per cent (fat) and 60 per cent (carbohydrate). The above utility model forms the basis for our analysis.

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[2] Formula [5] is optimized subject to [6]. The Lagrangian L is:

$$L=\left(d_{pf}^r\right)^{\alpha}\times\left(d_{ff}^r\right)^{\gamma}\times\left(d_{cf}^r\right)^{\varepsilon}\times\left(d_g^r\right)^{\beta}+\lambda\left\{V_{\max}-\left(d_{pf}^r\times v_{pf}^r\right)-\left(d_{ff}^r\times v_{ff}^r\right)-\left(d_{cf}^r\times v_{cf}^r\right)-\left(d_g^r\times v_g^r\right)\right\}.$$

A necessary condition is: $\frac{\partial L}{\partial d_{pf}^r}=0,\ \frac{\partial L}{\partial d_{ff}^r}=0,\ \frac{\partial L}{\partial d_{cf}^r}=0,\ \frac{\partial L}{\partial d_g^r}=0\ \ \frac{\partial L}{\partial \lambda}=0.$

The value in the optimal point is:

$$d_{pf}^r=\frac{\alpha}{\alpha+\beta+\gamma+\varepsilon}\times\frac{V_{\max}}{v_{pf}^r},d_{ff}^r=\frac{\gamma}{\alpha+\beta+\gamma+\varepsilon}\times\frac{V_{\max}}{v_{ff}^r},d_{cf}^r=\frac{\varepsilon}{\alpha+\beta+\gamma+\varepsilon}\times\frac{V_{\max}}{v_{cf}^r},d_g^r=\frac{\beta}{\alpha+\beta+\gamma+\varepsilon}\times\frac{V_{\max}}{v_g^r}.$$

4. Data Set and Assumptions

4.1 Data

As for the statistical data, we have used the Japanese statistics published by FAO-stat of the Ministry of Agriculture, Forestry and Fisheries. The data we use relates to the amount of demand and supply for agricultural products, which is quantified as output, import, export, gross domestic consumption, intensity, etc. The items included in these data are shown in Table 2. The data used for our calculations are roughly classified into three categories: cereals, stock-farm products, and bio-ethanol. The cereals category consists of several arable crops, such as rice, wheat, vegetable, fruit, etc. The stock-farm products category consists of meat and dairy foods such as beef, pork, chicken, egg, and others. And, finally, the bio-ethanol category consists of energy products.

Table 2. Agricultural product items

1. Various types of crops a. rice b. wheat c. barleycorn d. rye e. corn f. Sorghum bicolour g. other crops **2. Various types of potatoes** a. sweet potato b. white potato **3. Starch** **4. Pulses** a. soybean b. other beans **5. Various types of vegetables** a. brightly coloured vegetables b. other vegetables **6. Various types of fruit** a. orange b. apple c. other fruits **7. Various types of meat** a. beef b. pork c. chicken d. other meat e. whale **8. Eggs** **9. Milk and dairy products** a. self-consumption b. milk **c.** dairy products	c1. condensed milk c2. skim condensed milk c3. milk powder c4. skim milk c5. milk powder for infants c6. cheese c7. butter **10. Various types of fisheries** a. perishable and frozen goods b. smoked, salted fish guts and others c. canned food d. manure **11. Various types of seaweeds** **12. Various types of sugar** a. brown sugar b. refined sugar c. other sugar d. syrup **13. Oil and fats** a. vegetable fats and oils a1. soybean oil a2. colza oil a3. palm oil a4. other oils b. animal fats and oils b1. fish oil b2. beef tallow b3. other oils **14. Soybean paste** **15. Soy sauce** **16. Other foods** Mushrooms

4.2 Assumptions

In our simulation experiments, we have several food choices and we get a considerable amount of energy from nutrients. It is difficult to include all the nutrients. So we assumed that the total amounts of some nutrients taken in are equal to the volume of agricultural products made. This assumption is also commonly used by RIVM. Moreover, we contrive to create some categories based on a nutritional science point of view in our paper.

It will come as no surprise to say that Japan is importing large quantities of fish and fish-related food from abroad in order to satisfy its needs. Therefore, some researchers warn not to underestimate this factor. However, from a nutrient point of view this is not seen as having a significantly disturbing effect. This is mainly because the amount of kcal of fish is only 5.5 per cent (the total kcal of consumption of fish is 142.4 kcal/per/day, and the total kcal of consumption of all nutrients is 2572.8 kcal/per/day). For this reason, we will calculate the optimal boundary of products excluding fish in this paper.

Furthermore, Japan is fully surrounded by sea, so we can regard Japan as a closed economy in our assumptions. These assumptions serve as a base in order to calculate whether Japan's arable land area is sufficient to satisfy its demand for energy.

4.3 Calculations

We attempt to simulate AEM with the STELLA systems dynamics software package, which is frequently used as user-friendly simulation software in this field. Our model uses data involving the land intensity to produce 1 kcal and nutrient energy to live a normal life.

First, we divide the data into three categories: protein, fat and carbohydrate. Then we process the original data which we introduced already in Table 1. The data used is from the MAFF (Ministry of Agriculture, Forestry and Fisheries, 2005) of Japan, and this explains why Japan was selected as the case study for this paper.

The model which has been constructed has four branches which consist of data for land intensity and nutrient energy. The intensity and energy data is on the left side of Figure 8. When multiplied, this data becomes land area data (similar to the middle line). Finally, the left side data – intensity and energy – middle line data – land area of four categories – is used to simulate an optimal solution path using the utility function.

Figure 8 is clearly a rather global figure. It includes many flow diagrams. It should be noted that Figure 9 is the core model in the original AEM. However, our conceptual model is based on the original AEM which was made by RIVM.

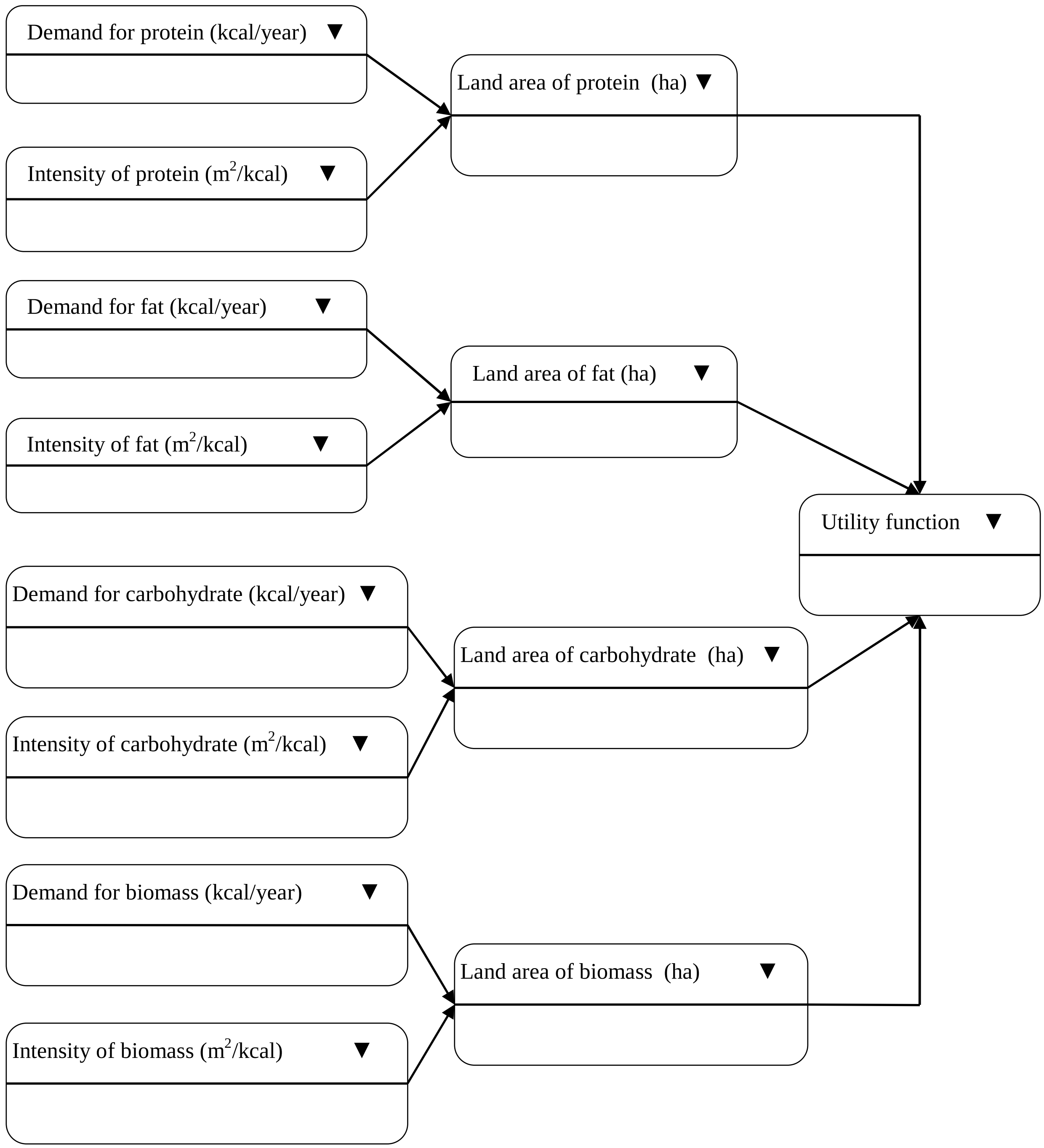


Figure 8. Flow diagram of AEM

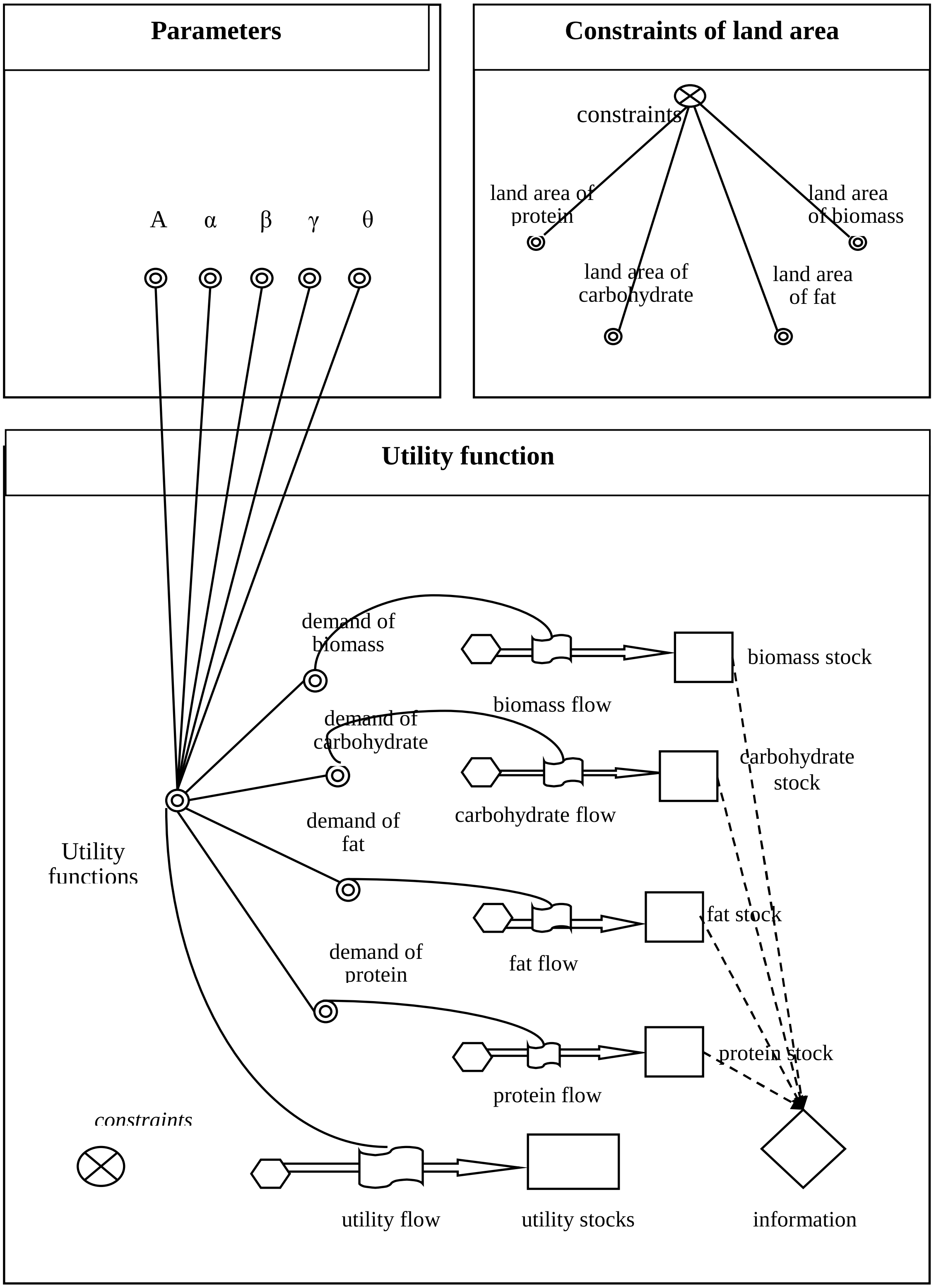


Figure 9. STELLA structure for our AEM simulations

5. Results of the Simulation Experiment

5.1 Simulation

We find as a result of the AEM simulations, as shown in Figure 11, that the utility function line is approximately 3.5e+013 kcal/Japan/year, even if the land area in the country constraint has an upper limit (see Figure 10). We can assume from our simulation that the energy demand of the Japanese people is higher than the energy potential which they can use. According to our simulation results, the maximum needs of the Japanese people for nutrients and biomass are more than can be derived from the real land area in Japan. This is shown in the Cobb-Douglas utility function in Figure 10.

The utility function is rapidly increasing and intersects the constraints of the available land area at an early stage. In brief, Japan might have to cultivate more land area in order to satisfy the demands of its population completely. However, in Japan it is difficult to extend the area of cultivated land, because it is a mountainous island country. It is thus a major problem for Japan to work out a policy that satisfies Japan as a whole. This is the only result under a basic utility function which has an unsaturated assumption.

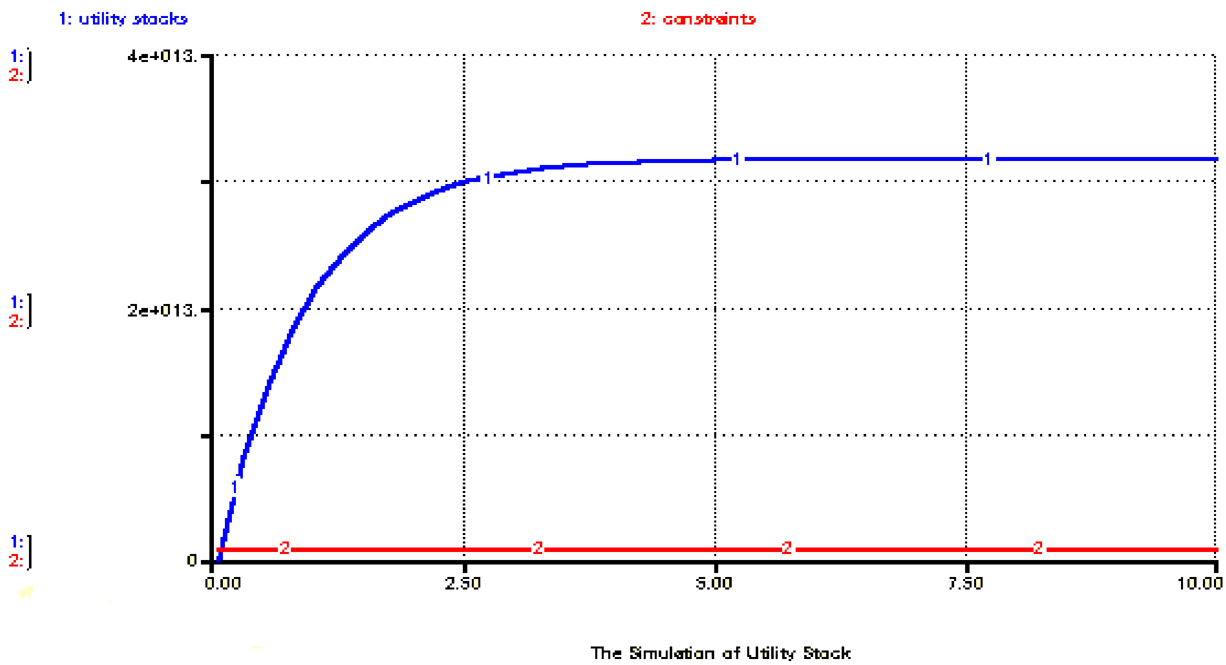


Figure 10. Simulation of utility function

Figure 11 shows the result that indicates the amount of stock for each category: protein, fat, carbohydrate and biomass. This simulation result shows whether our actual demand for nutrients is an appropriate rate or not, where 'appropriate rate' means the PFC rate. Japan tends to take energy mainly from carbohydrate and then fat, while protein comes last. A desirable PFC rate for the Japanese would be “protein 13 per cent, fat 27 per cent, carbohydrate 60 per cent”. As for the ranking of nutrients, it is likely that Japanese people do not have a balanced diet, and the rate of protein is more than the fat rate, even though it would be better to take less energy from protein than from fat. If Japanese people take as much nutrient energy as they need in a day, they may need to decrease protein nutrient energy in order to stay healthy.

However, this simulation is the result of assumptions using statistical data and ignores a substitution among foods. We will address these limitations in a follow-up study.

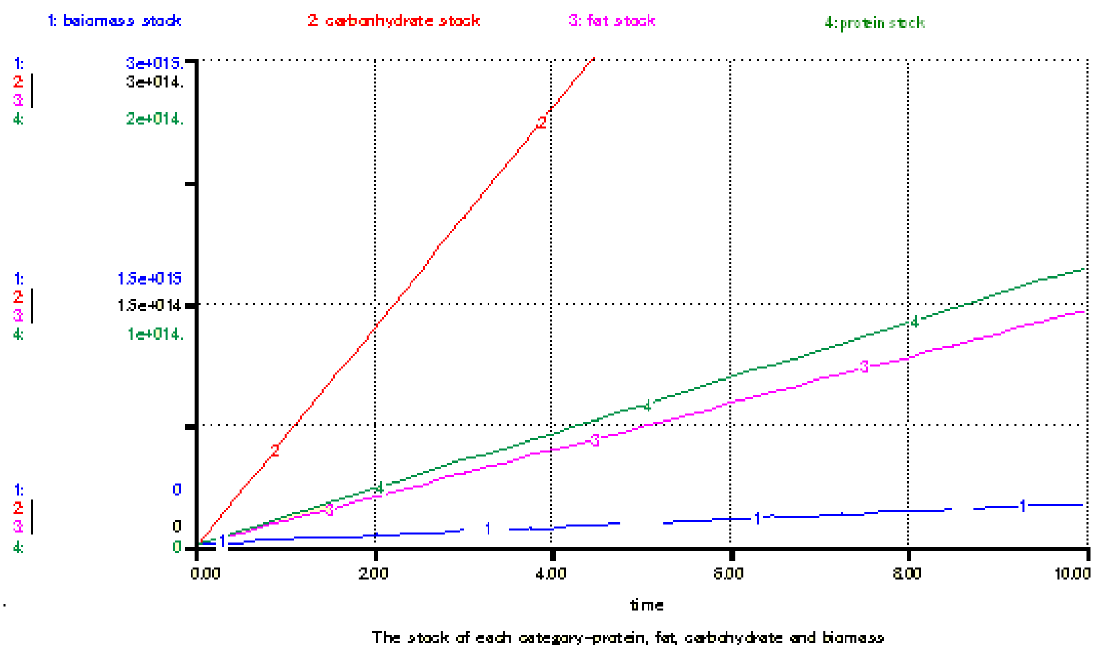
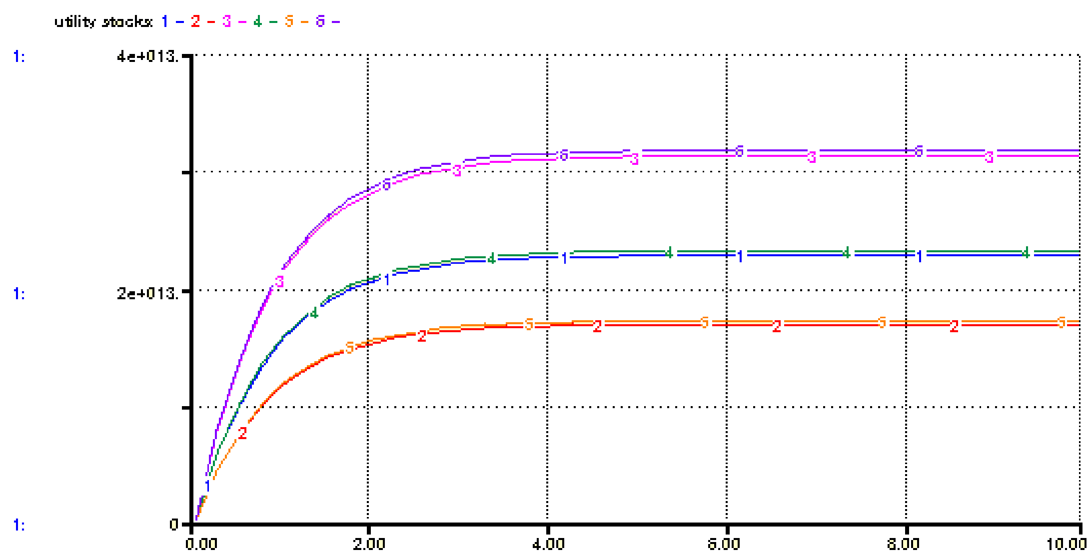


Figure 11. The energy stock of each category-protein, fat, carbohydrate and biomass

5.2 Sensitivity analysis

This result is simulated with static data under the assumption that the utility function is of a Cobb-Douglas type. Furthermore, the data we used entails other crops instead of biomass data. It is difficult to assess land area required for the production of biomass products as Japan is a sea-locked mountainous country. This is why we used the data on other crops as a substitute for biomass data. Recently, the Japanese government has been tackling biomass recycling associated with resource problems, setting up many pilot projects regarding biomass in Japan. If the results point out that producing biomass products such as fuel can be done more efficiently compared with the production of some foods as nutrients from a productivity point of view, Japan might choose to produce biomass products so as to cope with land resource problems.

Figure 12 shows the simulation results of a sensitivity analysis and a parameter table which indicates the different parameters of the Cobb-Douglas utility function. The assumed scenario for sensitivity analysis is that the demand for biomass will increase in the near future; therefore, we have to manage the production of nutrients and energy products like biomass. We focus on the biomass parameter "θ" and shift it from 0.25 to 0.50. Model 1 resembles the same pattern as in Figure 10. Models 1 and 4 have similar results and so do models 3 and 6 and models 2 and 5. Furthermore, we find that the biomass parameter makes the utility function divide into three patterns, while our model has a gap from about 3.1e+13kcal to 1.8e+13kcal. However, the volume of nutrients for the three categories is of the same order.



	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Biomass (θ)	*0.25*	*0.30*	*0.35*	*0.40*	*0.45*	*0.50*
Protein (α)	0.25	0.23	0.22	0.20	0.18	0.17
Fat (β)	0.25	0.23	0.22	0.20	0.18	0.17
Carbohydrate (γ)	0.25	0.23	0.22	0.20	0.18	0.17

Figure 12. Simulation results of sensitivity experiments

Finally, this simulation is the result of the biomass parameter in a Cobb-Douglas utility function. In the future we need to expand the model to consider both input and output data which have been used in other models.

6. Conclusion

We have obtained various interesting results from our simulation. First, the present land area available in Japan is not sufficient to satisfy Japanese demand for energy completely. The land which is required by Japan to satisfy its energy needs is several times larger than the actual land area. Second, the order of nutrients consumed by the Japanese, mainly carbohydrate followed by protein and fat, is not a preferable one. We might assume that recently Japanese people's preferences have shifted towards a Western meal made of meat and dairy food. Some researchers have labelled this phenomenon the "Westernization of Chinese Dietary Life". In addition, we tested the sensitivity of our model in order to check the robustness with several parameters of biomass and no critical problems emerged.

We conclude that Japan needs land use policies such as cultivation and reclamation in order to expand its land cover as it does not have enough land area to maximize its utility function. Therefore, the Japanese government should engage in such policies if it wants to satisfy the country as far as energy demand is concerned. Knowing the above, decisions have to be made in order to adjust the planted area's energy balance from a nutritional science aspect. In particular, the Japanese government may need to prohibit the production of some food which have high amounts of protein such as meat and dairy products, because the Japanese receive enough energy from protein already.

Finally, we described the design of the AEM and explained the simulation that has implications for land use policy. We can conclude, therefore, that the model in this paper gives us useful information regarding human welfare through utility functions and a desirable cultivation rate of usable land area.

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